Digital Color Management

ENCODING SOLUTIONS

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Foreword

Not many years ago, technical books on color were either printed entirely in black ink, or, if color was included at all, it was confined to a few color plates inserted as additions to the main text. *Digital Color Management: Encoding Solutions* is profusely illustrated with color throughout, and this demonstrates a revolution that has taken place in publishing. The graphic arts industry has developed color printing to the point where it is now economically possible to print textbooks in color and achieve very high quality. The availability of color in computer signals, in self-luminous display devices, and in printers has therefore led practitioners of desktop publishing to expect comparable results. But, in the printing industry, much technical development and human skill had to be used before consistently good results were obtained. Digital imaging currently faces the challenge of reaching a similar position. At first sight, it might seem that the endless flexibility provided by having signals in digital form should make all the problems easily solvable. That this is not so is illustrated by the plethora of different color management systems that have reached the market.

The complexity of the situation arises from the different input, monitoring, and output media involved, and the different objectives required for different applications. Thus the digital signals may originate from original artwork, from video cameras, from reversal films, from negative films, from *Photo CD* Discs, or from computer workstations. The final display may be a self-luminous monitor, a reflection print, a projected transparency, or a halftone graphic arts image. The application objective may be facsimile appearance, as in photocopying; or rendering like a conventional photographic system, as in

the need to provide various input-encoding and output-rendering options is gradually becoming more recognized.

Unfortunately, many problems remain. There still are misconceptions regarding the roles of color encoding specifications and color interchange specifications in color communication. There is confusion regarding the concept of encoding reference viewing conditions and the distinction between encoding reference conditions and actual input/output conditions. There also is confusion regarding specific concepts related to reference viewing conditions, such as the distinction between a reference illuminant and a reference adaptive white, the difference between media-relative colorimetry and brightness-adapted colorimetry, and the function of chromatic adaptation transforms. We sincerely hope that our book has helped to clarify these issues.

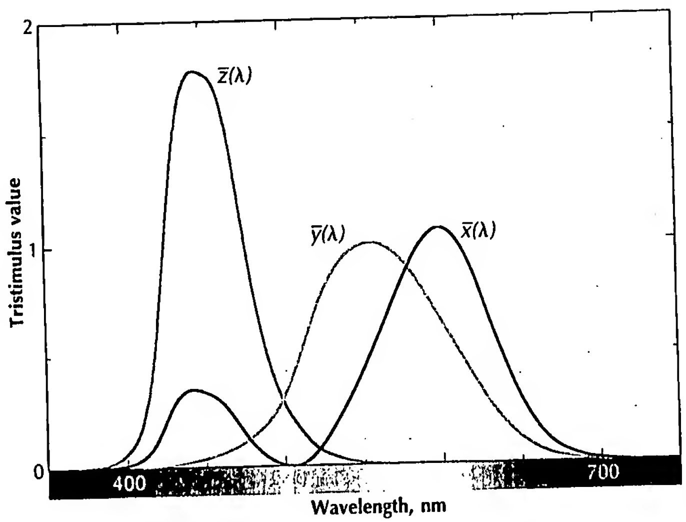
Of some concern to us is that encoding based on color appearance will be misunderstood as being sufficient to provide a complete solution to color encoding, just as encoding based on standard colorimetry has often been misunderstood to do so. As discussed in the text, appearance-based color encoding provides a means for integrating other color-encoding methods, but it is not a substitute for those methods. Encoding methods that can extract original-scene colorimetry from reproduced images, that can render images from negatives and digital still cameras, and that can re-render reproduced images in various ways are required in order to provide the complete array of input-interpretation options defined by the unified paradigm. Again, we hope that our book has helped to explain such issues.

Despite these concerns, we are optimistic that our ultimate goal of a unified color-management environment for the color-imaging industry someday will be reached. We envision a global environment encompassing a complete hierarchy of imaging systems and applications, from the simplest to the most sophisticated, all operating according to a single underlying paradigm. In this environment, the unifying force will be the unrestricted and unambiguous representation of color.

When this goal is realized, the full potential of digital color imaging will be achievable; and when that happens, imaging applications that we can only imagine today will be accepted as commonplace.

Appendix A: Colorimetry

References made throughout this book to *standard colorimetry*, or to *standard colorimetric values*, refer to colorimetric values determined according to CIE (Commission Internationale de l'Éclairage) recommended practices. All standard colorimetric values shown have been determined using the color-matching functions for the CIE 1931 Standard Colorimetric Observer (Fig. A1), whose color-matching characteristics are representative of those of the human population having normal color vision. The CIE 1931 Standard Colorimetric Observer is often referred to as the *2° Observer*, because test fields subtending a viewing angle of 2° were used in the judging experiments from which the color-matching functions were derived.



[Fig]ure A1
[Co]lor-matching [fun]ctions for the [CI]E 1931 Standard [Co]lorimetric [Ob]server.

The CIE also has defined the 1964 Supplementary Standard Colorimetric Observer (Fig. A2), often referred to as the *10° Observer*. The color-matching functions of the 10° Observer are used for colorimetric measurements and calculations related to relatively large areas of color. The color-matching functions of the 2° Observer are used for most colorimetric measurements and calculations related to pictorial and graphics imaging, where individual areas of color generally subtend relatively small viewing angles.

The 2° Observer color-matching functions are used in the calculation of CIE tristimulus values X, Y, and Z, which quantify the trichromatic characteristics of color stimuli. The X, Y, and Z tristimulus values for a given object (characterized by its spectral reflectance or transmittance) that is illuminated by a light source (characterized by its spectral power distribution) can be calculated for the 2° Observer (characterized by the appropriate set of CIE color-matching functions) by summing the products of these distributions over the visible wavelength (λ) range (usually from 380 to 780 nm, at 5-nm intervals). The calculation of X, Y, and Z values is shown in Eqs. {A1}, and the basic procedure is diagrammed in Fig. A3.

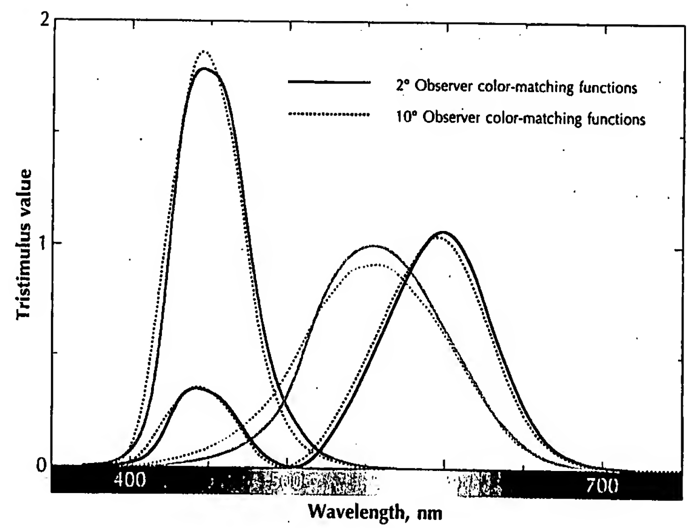


Figure A2
Color-matching functions defined for the CIE 1964 Supplementary Standard Colorimetric Observer (10°) and the CIE 1931 Standard Colorimetric Observer (2°).

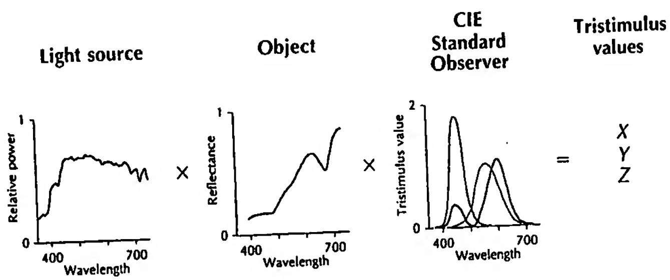
$$X = k \sum_{\lambda=380}^{780} S(\lambda)R(\lambda)\bar{x}(\lambda)$$

$$Y = k \sum_{\lambda=380}^{780} S(\lambda)R(\lambda)\bar{y}(\lambda) \qquad \{A1\}$$

$$Z = k \sum_{\lambda=380}^{780} S(\lambda)R(\lambda)\bar{z}(\lambda)$$

where X, Y, and Z are the CIE tristimulus values; $S(\lambda)$ is the spectral power distribution of the light source; $R(\lambda)$ is the spectral reflectance or transmittance of the object; $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$ are the color-matching functions of the 2° Observer; and k is a normalizing factor. By convention, k generally is determined such that $Y = 100$ when the object is a *perfect white*. A perfect white is an ideal, nonfluorescent, isotropic diffuser with a reflectance (or transmittance) equal to unity throughout the visible spectrum.

igure A3
alculation of CIE
YZ tristimulus
alues.



Chromaticity coordinates x, y, and z are derived from the tristimulus values as follows:

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z} \qquad \{A2\}$$

$$z = \frac{Z}{X+Y+Z}$$

The CIE also has recommended the use of other coordinate systems, derived from XYZ, in which visual differences among colors are more uniformly represented. These systems include the CIE 1976 u', v' uniform-chromaticity-scale diagram and the CIE 1976 $L^*a^*b^*$ (CIELAB) color space.

In this book, u', v' diagrams (Fig. A4) are used for describing the chromaticities of color primaries, the chromaticity boundaries of color gamuts, and the results of applying chromatic adaptation transformations. The chromaticity values u' and v' are computed from XYZ values as follows:

$$u' = \frac{4X}{X+15Y+3Z} \qquad \{A3\}$$

$$v' = \frac{9Y}{X+15Y+3Z}$$

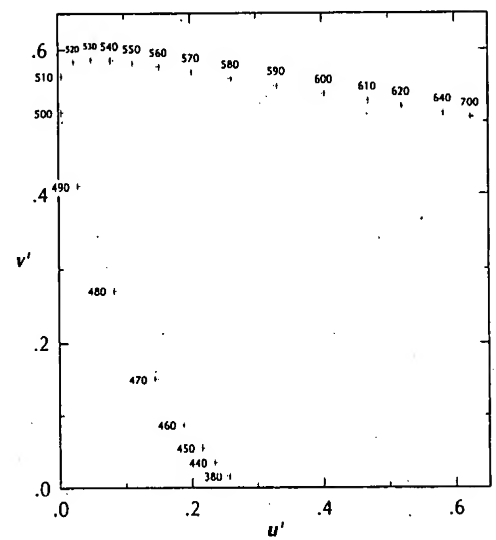


Figure A4
CIE u', v' chromaticity diagram.

Also in this book, CIELAB values are used for making comparisons of colorimetric color reproductions and for describing device and media color gamuts in three dimensions. CIELAB L^*, a^*, and b^* values are computed from the tristimulus values X, Y, and Z of a stimulus, and the tristimulus values X_n, Y_n, and Z_n of the associated reference white, as follows:

$$L^* = 116\left(\frac{Y}{Y_n}\right)^{(1/3)} - 16 \qquad \text{for } \frac{Y}{Y_n} > 0.008856$$

$$L^* = 903.3\left(\frac{Y}{Y_n}\right) \qquad \text{for } \frac{Y}{Y_n} \le 0.008856$$

and

$$a^* = 500\left[f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right)\right] \qquad \{A4\}$$

$$b^* = 200\left[f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right)\right]$$

where

$$f\left(\frac{X}{X_n}\right) = \left(\frac{X}{X_n}\right)^{(1/3)} \qquad \text{for } \frac{X}{X_n} > 0.008856$$

$$f\left(\frac{X}{X_n}\right) = 7.787\left(\frac{X}{X_n}\right) + \left(\frac{16}{116}\right) \qquad \text{for } \frac{X}{X_n} \leq 0.008856$$

$$f\left(\frac{Y}{Y_n}\right) = \left(\frac{Y}{Y_n}\right)^{(1/3)} \qquad \text{for } \frac{Y}{Y_n} > 0.008856$$

$$f\left(\frac{Y}{Y_n}\right) = 7.787\left(\frac{Y}{Y_n}\right) + \left(\frac{16}{116}\right) \qquad \text{for } \frac{Y}{Y_n} \leq 0.008856$$

$$f\left(\frac{Z}{Z_n}\right) = \left(\frac{Z}{Z_n}\right)^{(1/3)} \qquad \text{for } \frac{Z}{Z_n} > 0.008856$$

$$f\left(\frac{Z}{Z_n}\right) = 7.787\left(\frac{Z}{Z_n}\right) + \left(\frac{16}{116}\right) \qquad \text{for } \frac{Z}{Z_n} \leq 0.008856$$

Throughout the book, colorimetric comparisons of original and reproduced color stimuli are illustrated in terms of vector arrows on CIELAB a^*, b^* diagrams, such as that shown in Fig. A5. In that diagram, the a^*, b^* coordinates of the original color stimuli are represented by the + marks at the tails of the vector arrows. The heads of the arrows represent the coordinates of the corresponding reproduced color stimuli. The lengths of the connecting vectors indicate the magnitudes of the *chromatic* (hue and chroma) differences between the original stimuli and their reproductions. Note, however, that these vectors alone do not completely describe the *colorimetric* differences of the stimuli. Differences in L^* are part of the total colorimetric difference, and L^* differences are not shown on a CIELAB a^*, b^* diagram.

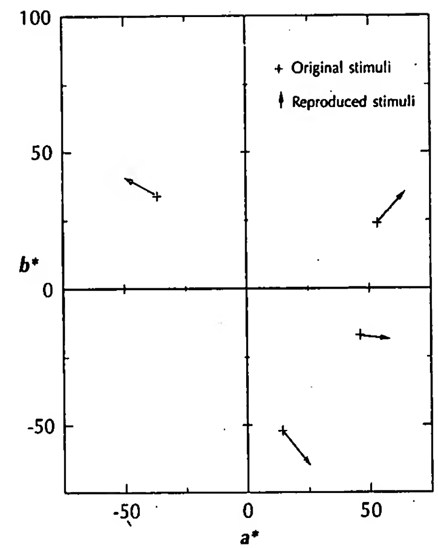


Figure A5
In CIELAB a^*, b^* diagrams such as this, the length of a vector arrow connecting two stimuli indicates their chromatic difference.